Living Solar Energy!

Project: SCF9 – ValiColl

Solar-Experience
Solar Thermal

Content:

1. Target
2. Methodology
3. Practical implementation
4. Results
5. Conclusion and outlook

Participants:

SPF INSTITUT FÜR SOLARTECHNIK

Fraunhofer ISE

IGTE

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Target

1. Validation of performance parameters of Quasi-Dynamic (QD) and Steady-State (SS)-Testing of ISO 9806 by an additional single test sequence

   expected benefits:

   - reduction of the deviation of the performance parameter sets due to different influences (test methods, test institutes, locations, persons, etc.)

   - one day measurement for complaint procedure

2. Option to determine the whole set of parameters using only this method

   expected benefits:

   - reducing testing time

   - reducing testing expenses

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Methodology

Principle:

Power measurement of a collector day with high irradiation sum (not necessarily blue sky), increasing inlet temperature and evaluation of the energy balance for 3 sub-intervals and the total interval.

Requirements:

1. *Measuring period 1 day from 1 h before sunrise to 1 hour after sunset*
2. *Irradiation sum: > **6,5** kWh/m²*
3. *Temperature range of inlet temperature from ambient to a max. temperature dependent on the heat loss category of the collector **and ambient temperature***
4. *Collector facing **equator**, tilt angle adapted to have normal incidence at solar noon*

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Practical implementation adaptation to different collector types

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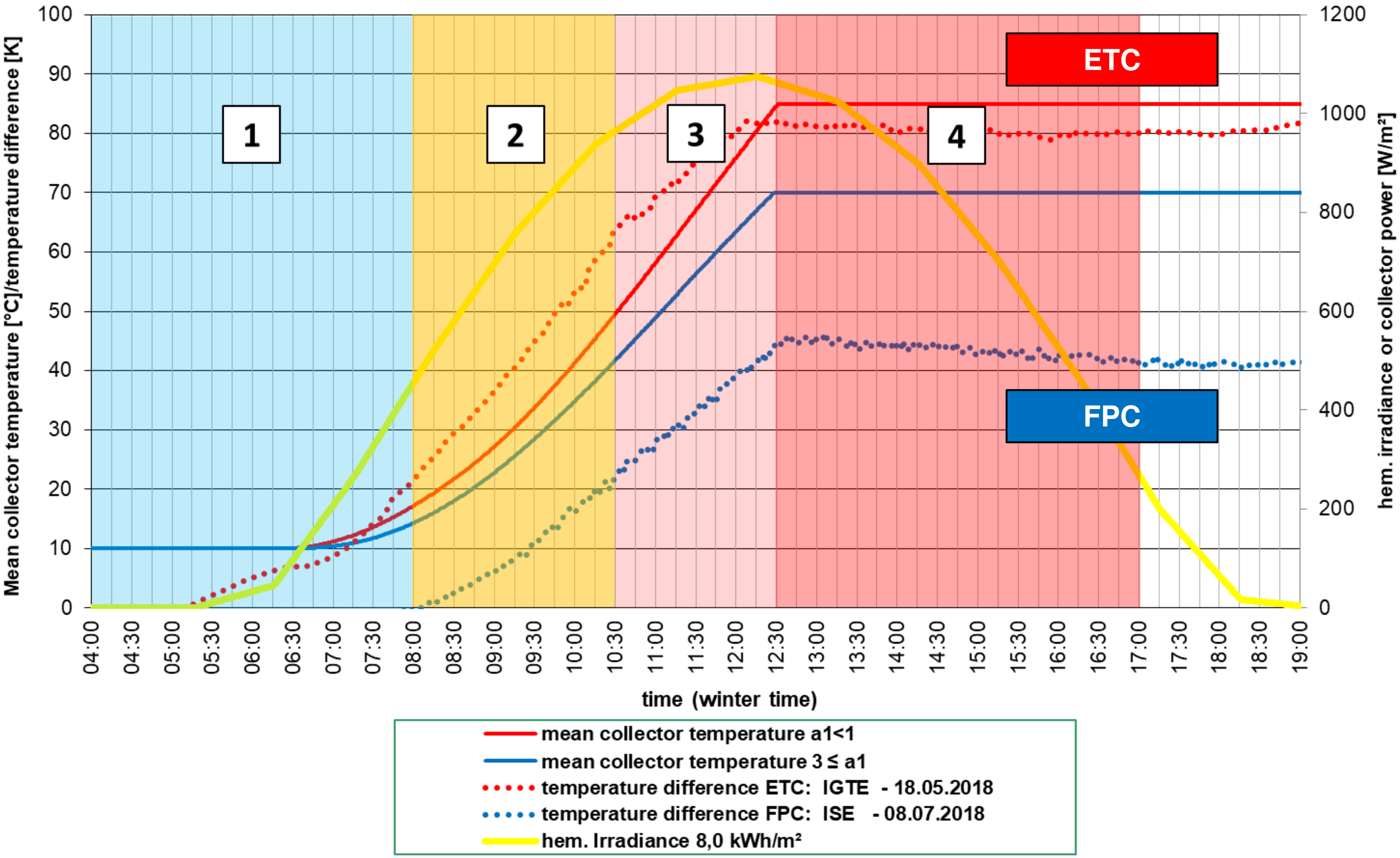
Validation sequence: Theory of temperature curve and evaluation intervals



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Data evaluation

Evaluation principle: Uniform data sets and comparison with simulation

1. Validation of data sets of test institutes according to validation sequences measurements

- Measured values of the institutes converted to averaged minute values and related per m^2 gross area
- Negative collector output set to 0
- Post-simulation in minute steps with heat capacity C/A
- Evaluation of the energy balance for different intervals:
  Interval 1: 04:00 to 08:00
  Interval 2: 08:00 to 10:30
  Interval 3: 10:30 to 12:30
  Interval 4: 12:30 to 17:00
- Evaluation of the relevant overall balance from 08:00 to 17:00

2. Determination of parameters sets from the validation sequences

- Post-simulation in minute steps using calculated heat capacity C/A of the Solar Keymark data sheet
- Fit principle: <2% deviation between simulation and measurement in the intervals 2 to 4. Interval 1 was only considered qualitatively due to the low power and the associated larger measurement error. The deviation of the energy balance from 08:0 to 17:00 should be < 0.5 %.
- Criterion for fit curve deviation: For the total interval, the sum of the absolute amounts of the deviations Measurement - Simulation was determined $\sum_{8:00}^{17:00} |q_m - q_s|$ and minimized.
- Determination of diffuse IAM Kd:
  a) for general fit: calculated according to ISO 9806 (ScenoCalc) – not presented
  b) for optimized general fit: selected (without calculation) for best possible fit

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Graphical assessment Vali T1 (QD)

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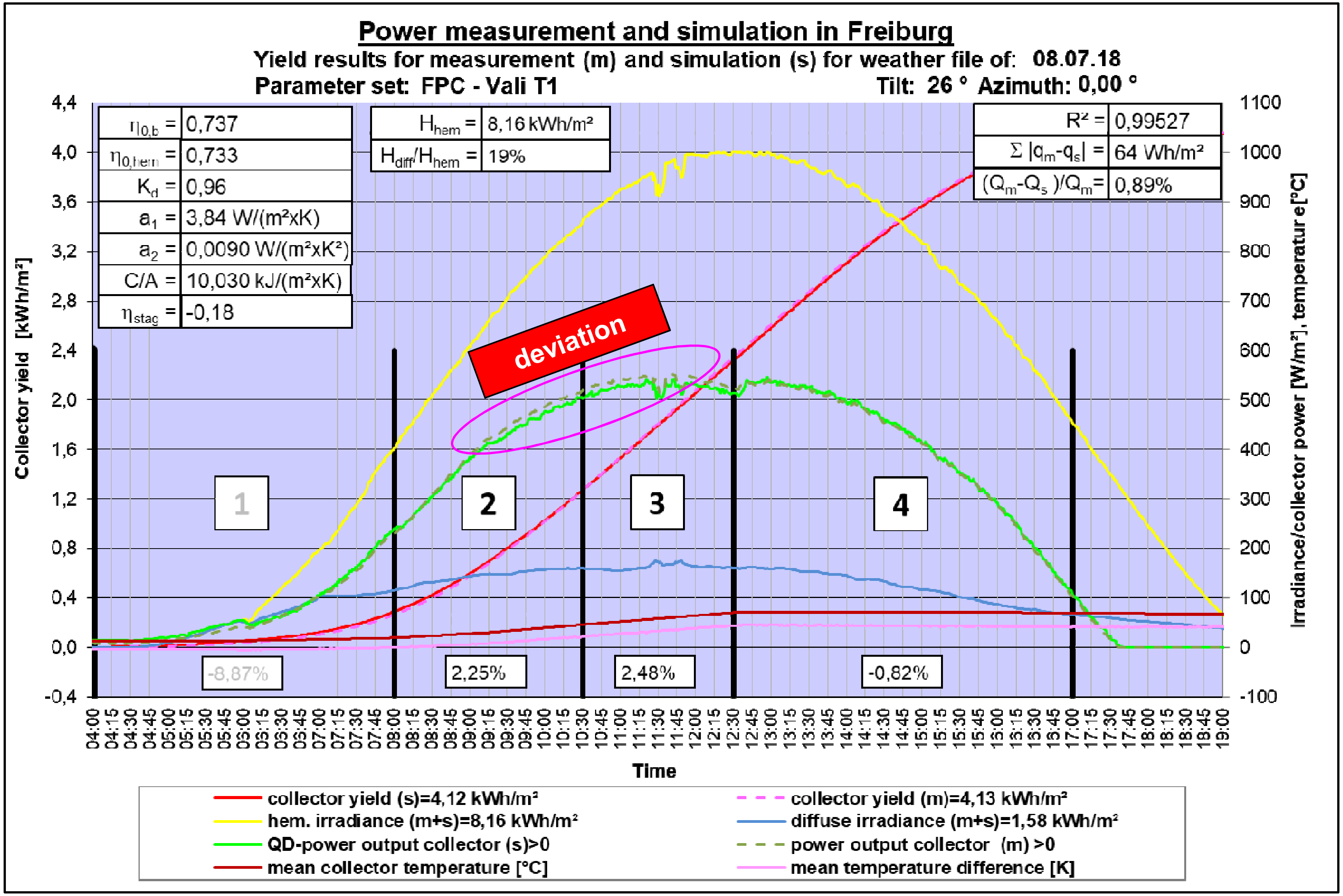

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Graphical assessment Vali T2 (SS)

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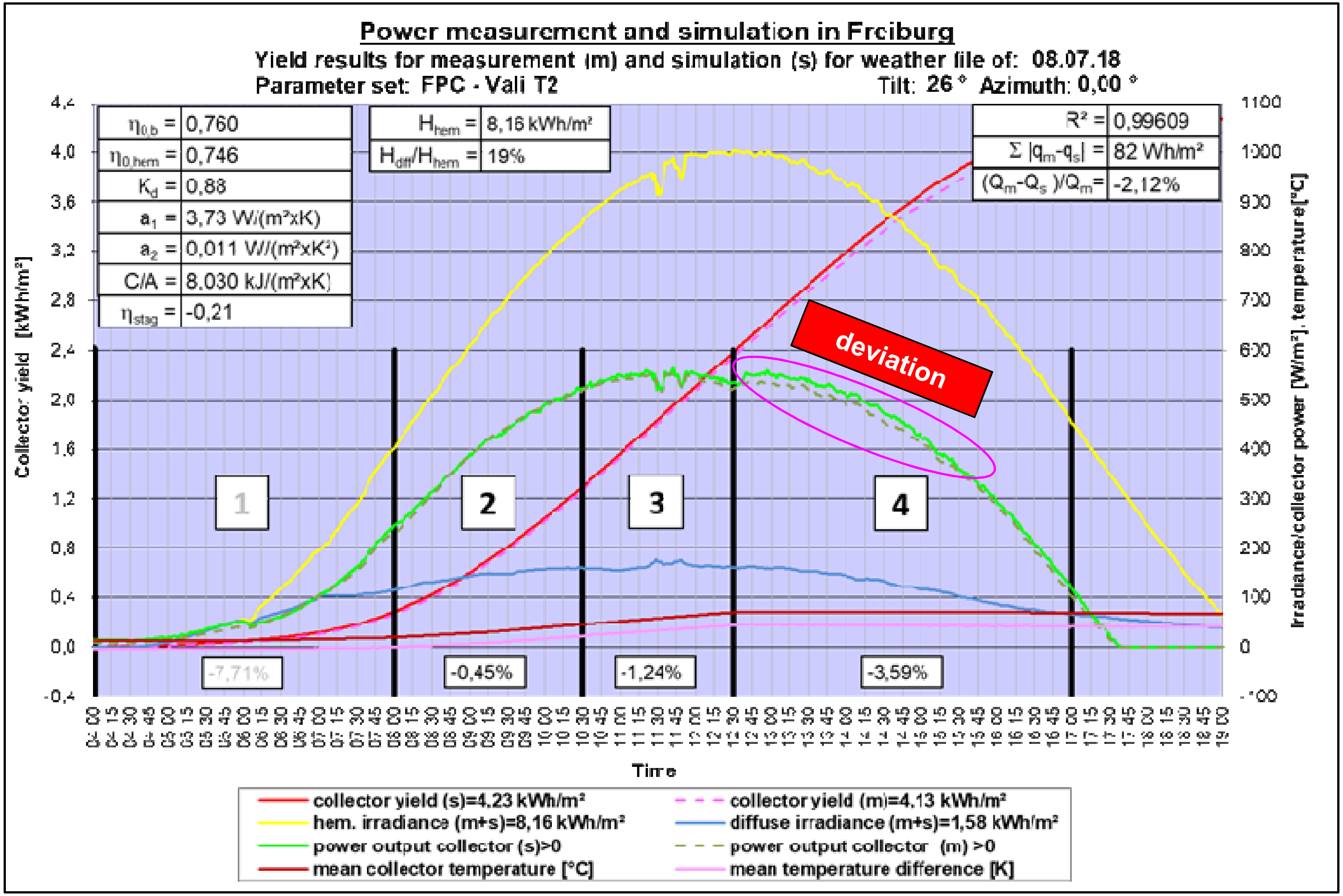

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Graphical assessment Vali T3 (QD)

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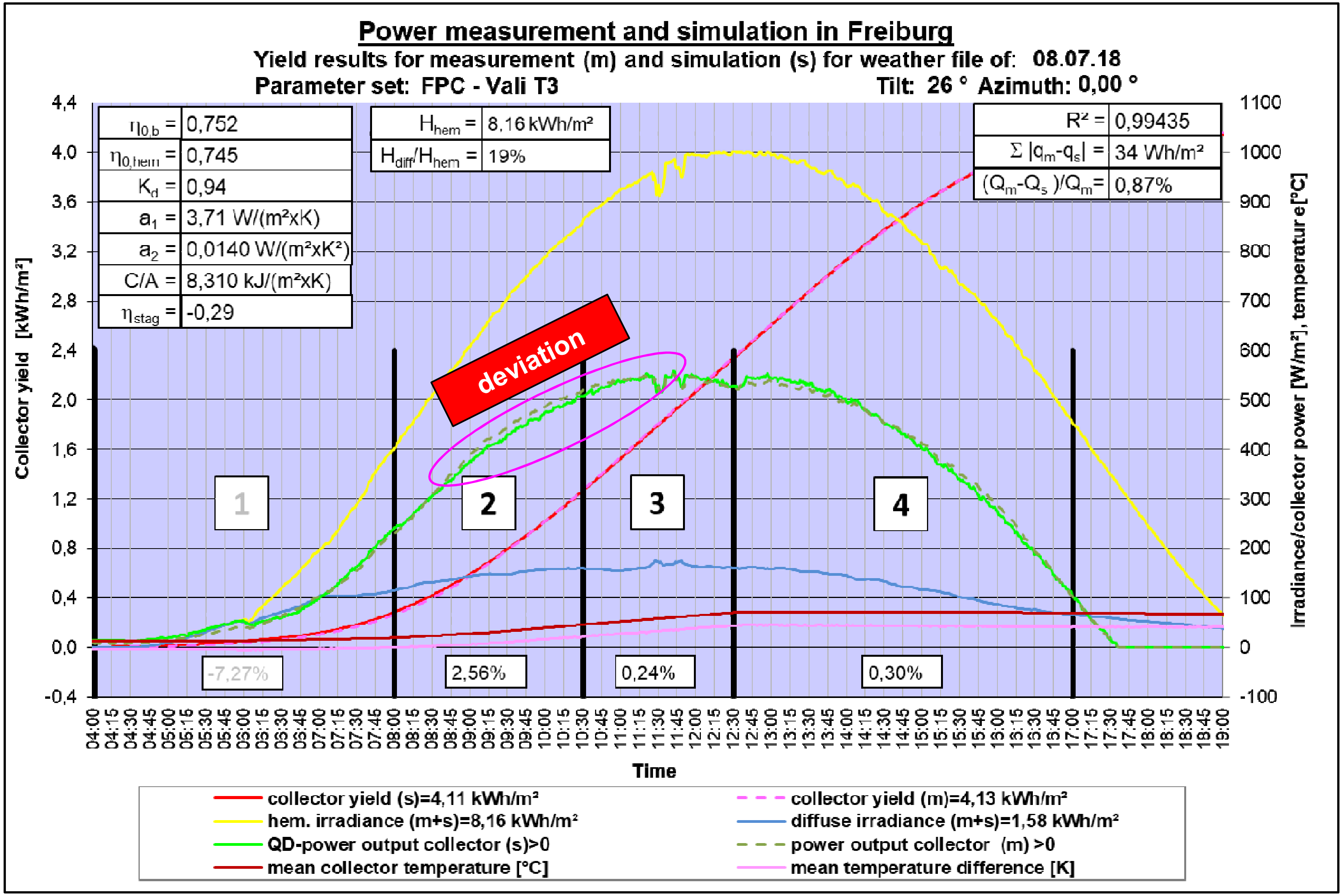

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Graphical assessment Vali-opt. Fit-a

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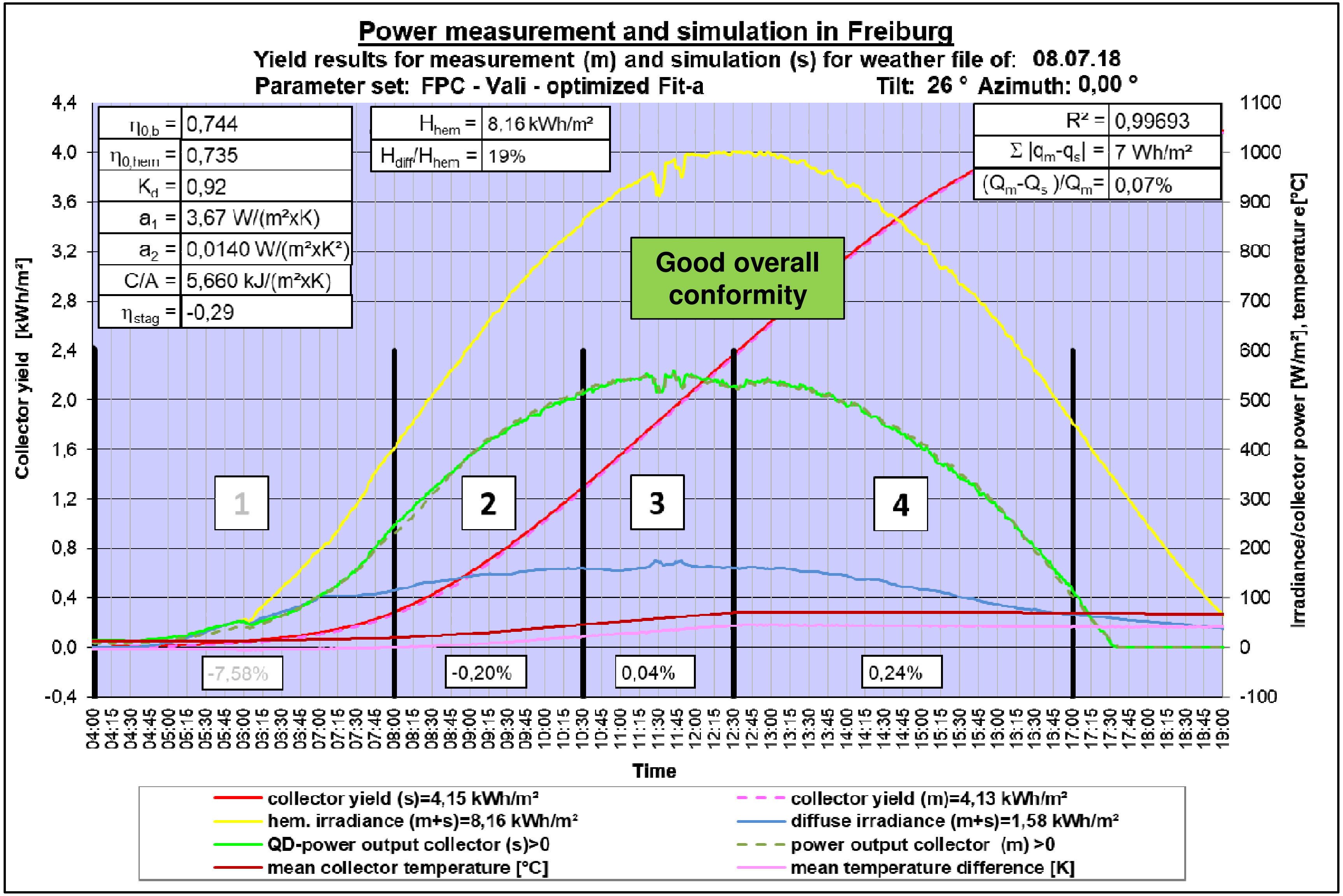

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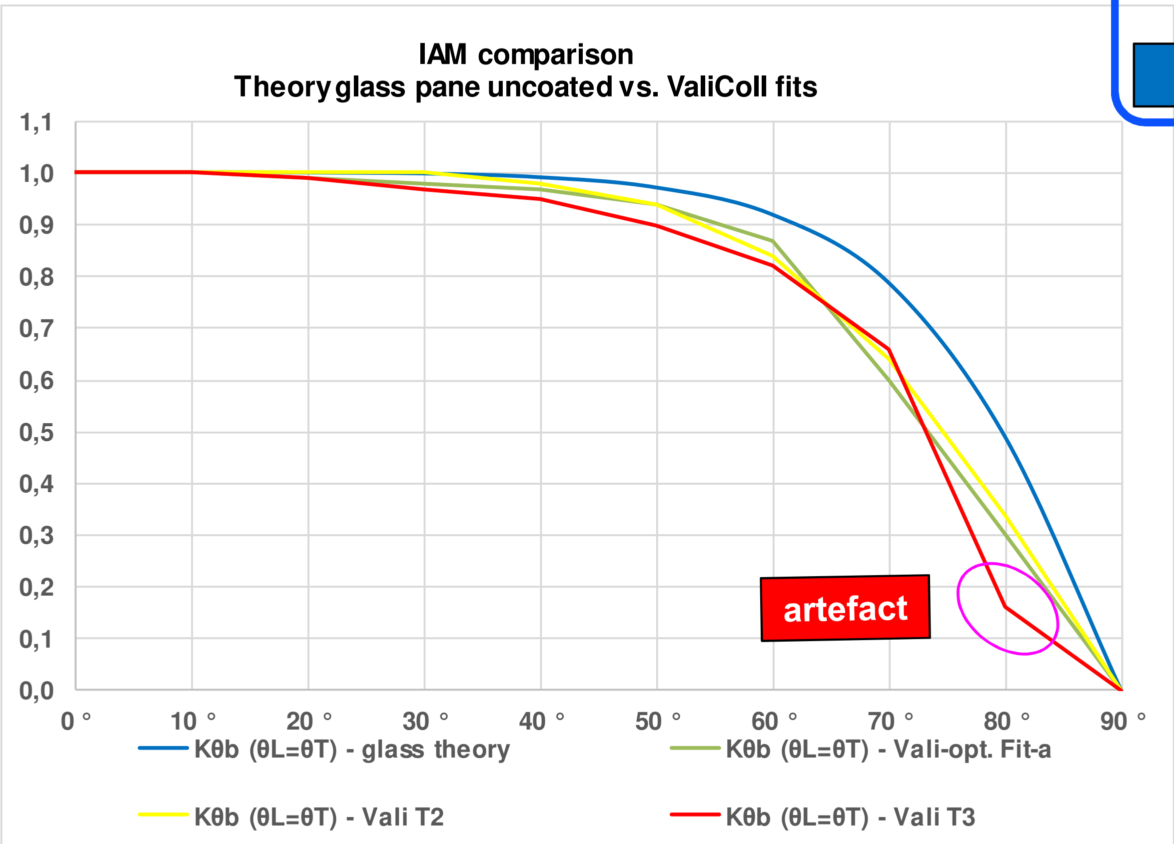
Summary IAM

	IAM - beam: $K_{\theta b}$										IAM - diffuse: K_d	
Incidence angle	0 °	10 °	20 °	30 °	40 °	50 °	60 °	70 °	80 °	90 °	calculated	adapted
$K_{\theta b}$ ($\theta_L=\theta_T$) - glass theory	1,000	1,000	1,000	0,997	0,990	0,971	0,918	0,787	0,489	0,000	0,92	
$K_{\theta b}$ ($\theta_L=\theta_T$) - Vali-opt. Fit-a	1,000	1,000	0,990	0,980	0,970	0,940	0,870	0,600	0,300	0,000	~~0,87~~	0,92
$K_{\theta b}$ ($\theta_L=\theta_T$) - Vali-T1	1,000	1,000	1,000	1,000	0,990	0,950	0,820	0,650	0,330	0,000	~~0,88~~	0,96
$K_{\theta b}$ ($\theta_L=\theta_T$) - Vali T2	1,000	1,000	1,000	1,000	0,980	0,940	0,840	0,640	0,340	0,000	0,88	
$K_{\theta b}$ ($\theta_L=\theta_T$) - Vali T3	1,000	1,000	0,990	0,970	0,950	0,900	0,820	0,660	0,160	0,000	~~0,84~~	0,94

SS

QD



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Comparison of FPC results

collector-fit	Vali optimized Fit-a	Vali T1	Vali T2	Vali T3
$\eta_{o,b}$	0,744	0,737	0,760	0,752
$\eta_{o,hem}$	0,735	0,733	0,746	0,745
k_d	0,92	0,96	0,88	0,94
a_1	3,670 W/(m²xK)	3,840 W/(m²xK)	3,730 W/(m²xK)	3,710 W/(m²xK)
a_2	0,014 W/(m²xK²)	0,009 W/(m²xK²)	0,011 W/(m²xK²)	0,014 W/(m²xK²)
C/A	5,660 kJ/(m²xK)	10,030 kJ/(m²xK)	8,030 kJ/(m²xK)	8,310 kJ/(m²xK)
η_{stag}	-0,29	-0,18	-0,21	-0,29
ACO at 25 °C	703 kWh/m²	715 kWh/m²	710 kWh/m²	711 kWh/m²
ACO at 50 °C	444 kWh/m²	455 kWh/m²	455 kWh/m²	448 kWh/m²
ACO at 75 °C	253 kWh/m²	269 kWh/m²	270 kWh/m²	254 kWh/m²
ACO rel. at 25 °C	100%	102%	101%	101%
ACO rel. at 50 °C	100%	102%	102%	101%
ACO rel. at 75 °C	100%	106%	107%	100%

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Graphical assessment ETC - certified

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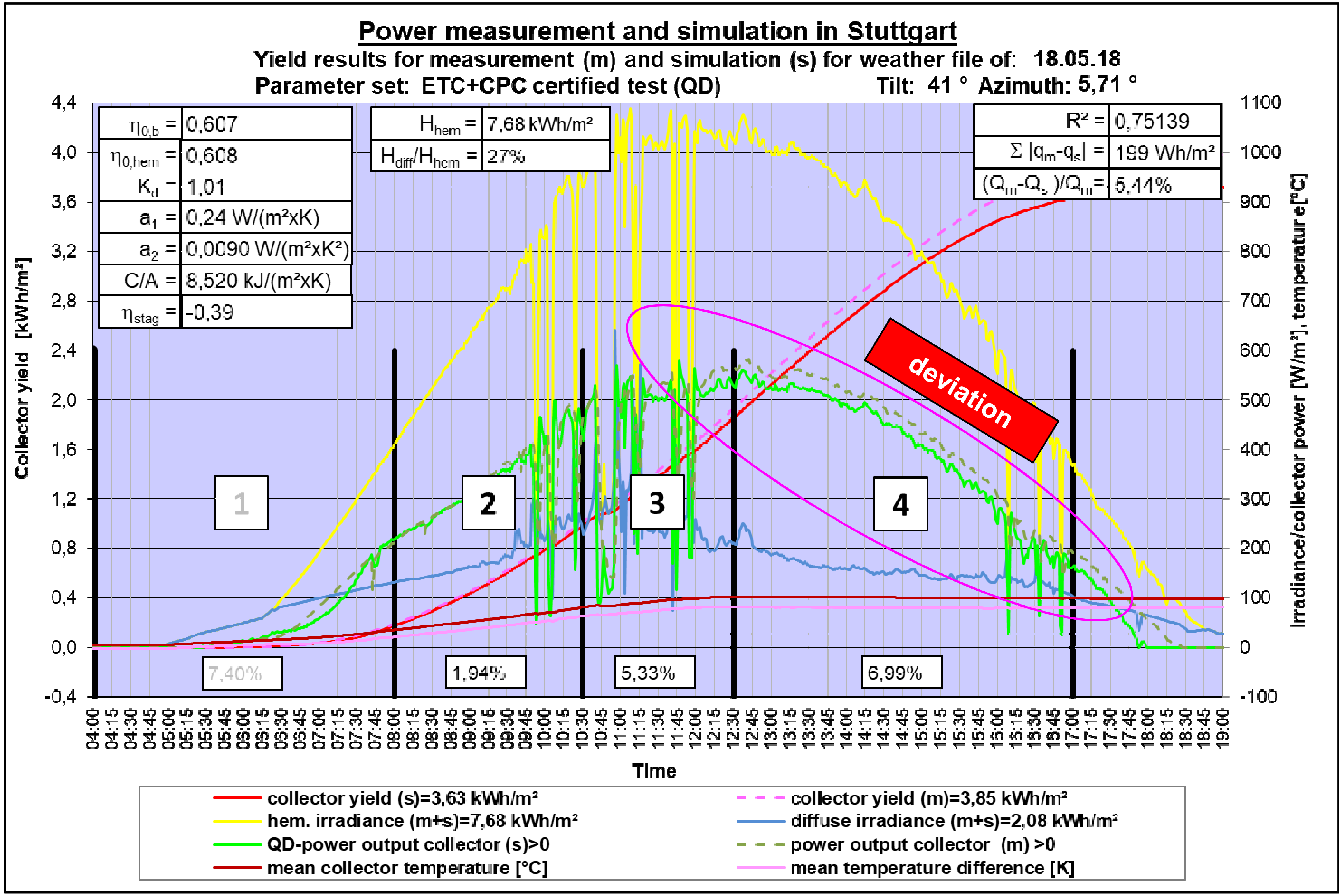

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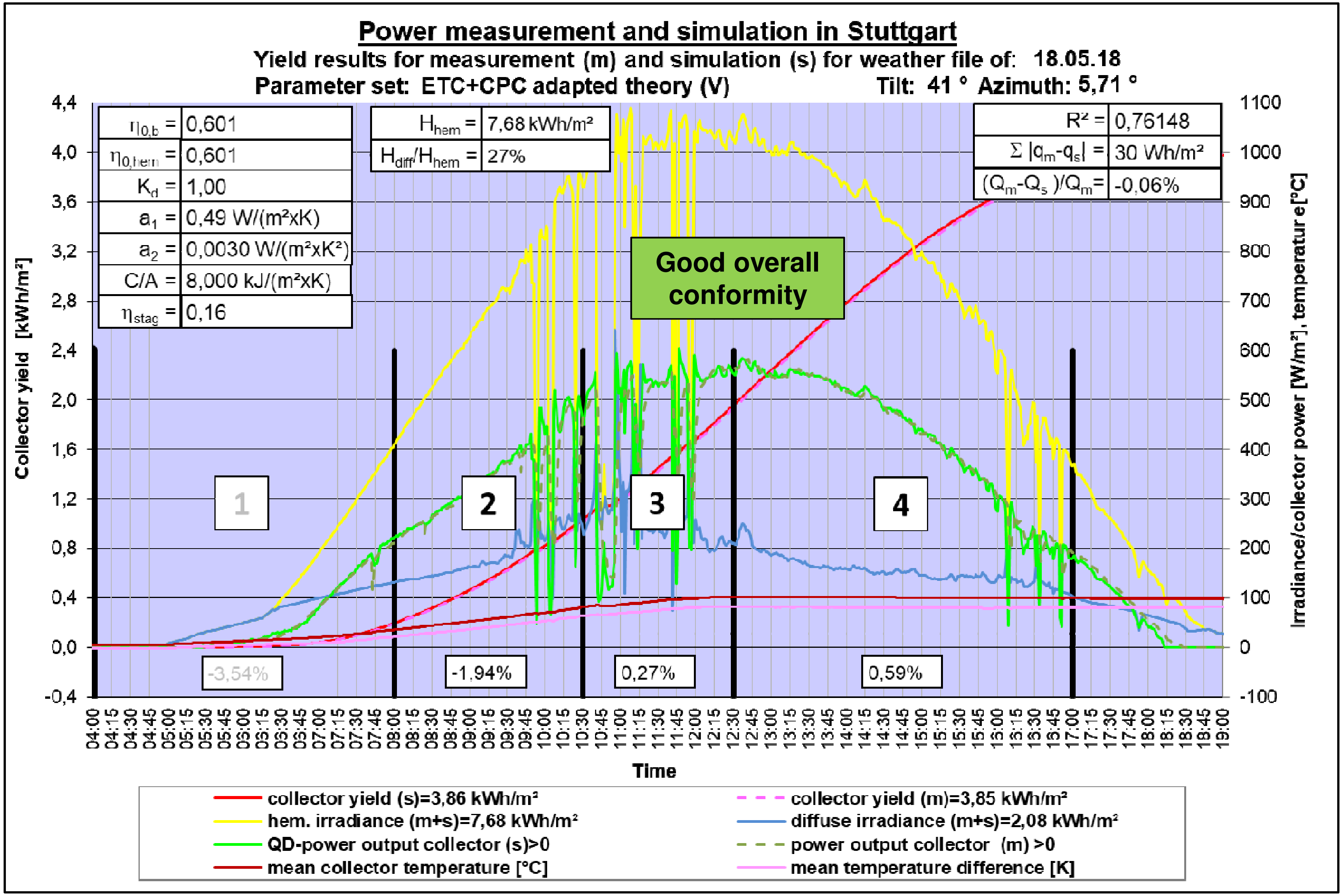
Graphical assessment ETC - validated



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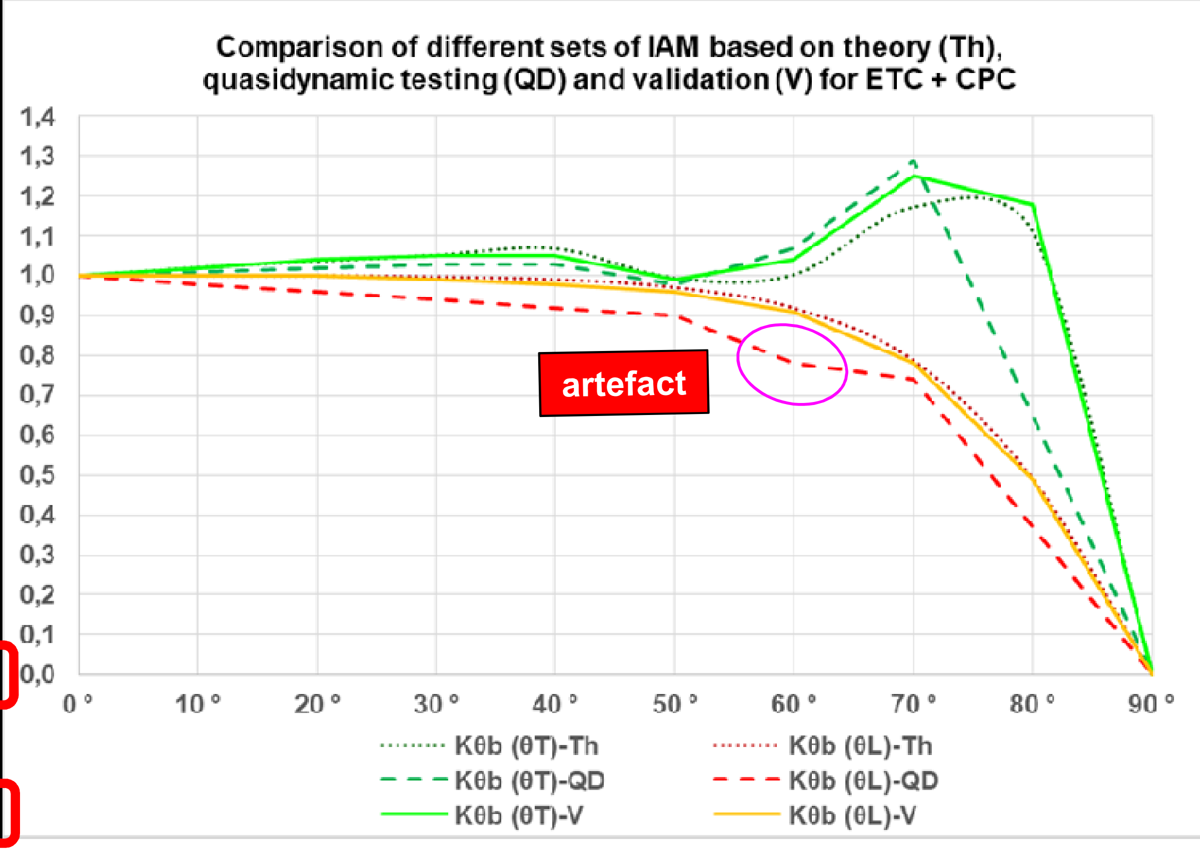
Comparison of ETC results

collector-fit	ETC+CPC certified test (QD)	ETC+CPC adapted theory (V)
$\eta_{o,b}$	0,607	0,601
$\eta_{o,hem}$	0,608	0,601
k_d	1,01	1,00
a_1	0,240 W/(m²xK)	0,490 W/(m²xK)
a_2	0,009 W/(m²xK²)	0,003 W/(m²xK²)
C/A	8,520 kJ/(m²xK)	8,000 kJ/(m²xK)
η_{stag}	-0,39	0,16
ACO at 25 °C	733 kWh/m²	733 kWh/m²
ACO at 50 °C	669 kWh/m²	674 kWh/m²
ACO at 75 °C	580 kWh/m²	610 kWh/m²
ACO rel. at 25 °C	100%	100%
ACO rel. at 50 °C	100%	101%
ACO rel. at 75 °C	100%	105%



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Measured results - efficiency

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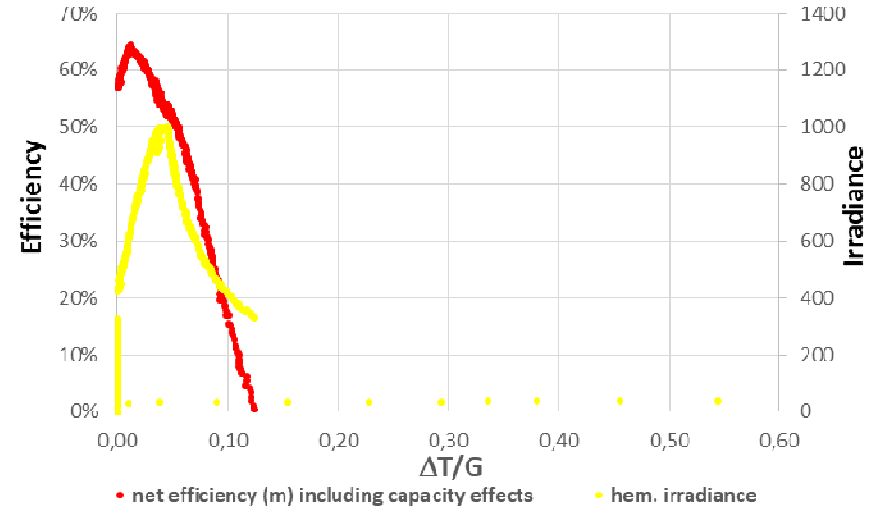
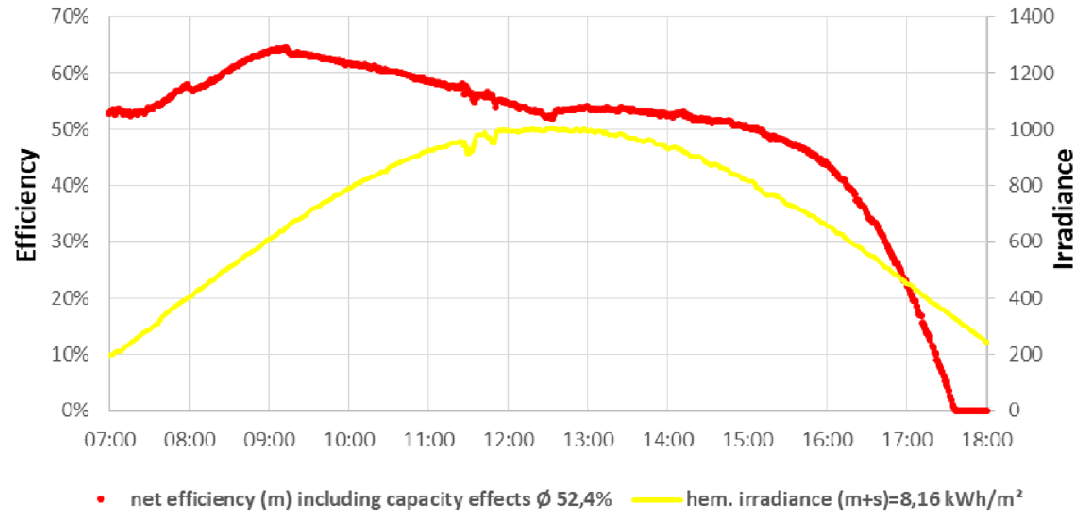
FPC

Efficiency vs. ΔT/G in Freiburg 08.07.18

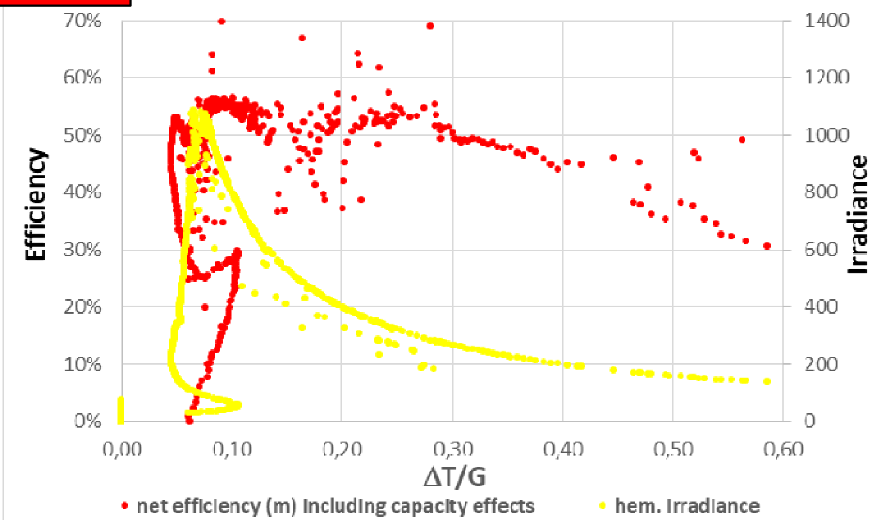


Efficiency vs. time in Freiburg 08.07.18

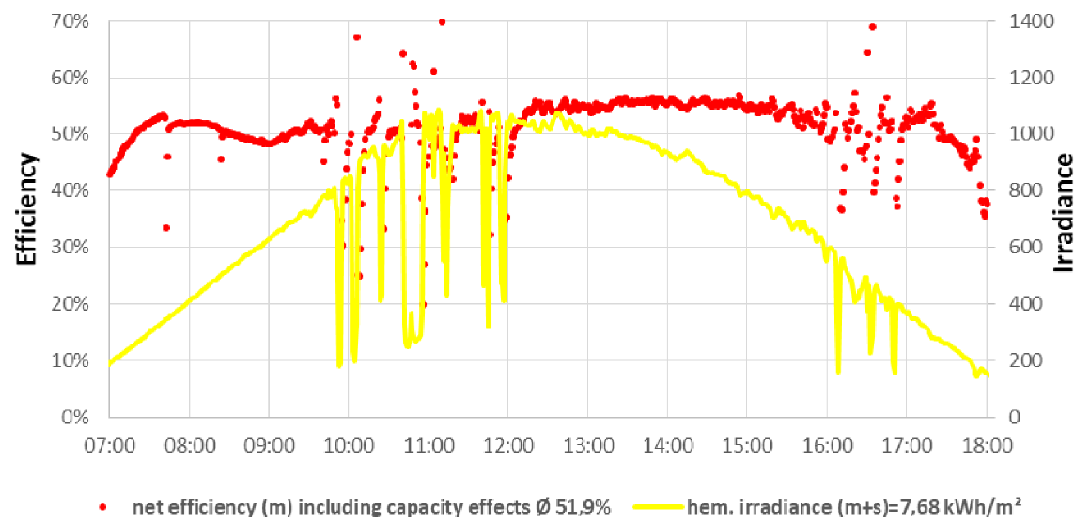


ETC

Efficiency vs. ΔT/G in Stuttgart 18.05.18



Efficiency vs. time in Stuttgart 18.05.18



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Lessons learnt

The parameter model from ISO 9806 is only a rough description of the real physics of a collector. All parameters are interconnected and therefore also vary depending on the measuring method and conditions

Results:

1. Measurements at higher collector temperature improve the accuracy of the parameter set
2. A validation sequences shows remaining deficits of the parameter fits → parameters can be improved
3. The maximum temperature for validation should be selected by manufacturers and limits the application range
4. IAM should be cross-checked with theoretical values to prevent artefacts
5. Energy gain at diffuse radiation is underestimated → adapted Kd , higher than calculated, is the key
6. Based on theory and a validation sequence at high irradiation conditions (>6,5 kWh/(m^{2}d)) a parameter set can be found which has a similar precision like one with a QD or SS test.
7. A one day measurement (validation sequence) can be used to show conformity with the Keymark results

Next steps

1. Introduction of the validation sequence into ISO 9806
   Shall make results of QD and SS more consistent and allow Kd adaptation within defined limits generally
2. Development of complaint procedure based on the validation.
   E.g. a maximum allowed deviation of 5% less energy output in each sub interval 2, 3 and 4 at a minimum of 6,5 kWh/m^2 irradiation could be the limit for a one day measurement

A follow up SCF project makes sense!

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What else?

Validation generally creates confidence in solar thermal technology for

consumers,

manufacturers

test institutes, certification

…. and

makes a solar collector a competitive heat generator

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